



Fox-1E (RadFxSat-2) Telemetry and Whole Orbit Data Simulation

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Review: Fox-1 DUV Telemetry

- | Fox-1A through Fox-1D are FM Repeater Satellites
 - » Only a single downlink frequency
 - » Telemetry sent as DUV
 - » There is a high speed mode too
- | DUV = Data Under Voice
 - » Essentially FSK at a slow rate (200 bps)
- | FSK on FM?
 - » What happens when you shift the frequency on FM?
 - » Demodulated wave varies according to the carrier frequency shift
 - » So FSK adds sound to the audio below 2-300Hz



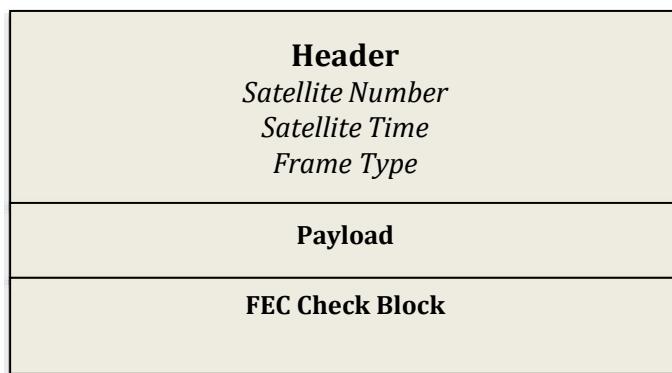
- » Essentially FSK at a slow rate (200 bps)
- » In baseband (audio) it appears as a signal under 300 Hz

CTCSS Tone	Voice	Uplink
Telemetry	Voice	Downlink



Review: DUV Data Frame

- | This is what a DUV frame looks like
- | Takes about 5 seconds to send
- | About 1000 bits, including 32 check bytes for Forward Error Correction, and 8b10b encoding





Review: Forward Error Correction

- | FEC designed by Phil Karn, KA9Q et al
 - » (See citation in this paper in the Proceedings)
 - » Uses Reed Solomon (255,223)
 - Send 255 bytes, of which 223 are data (32 check info)
- | Do not use all 223 bytes!
- | Designed for typical fades seen in our expected packets (we could have made them longer)
- | One 32-byte check block suffices for one DUV frame



Review: 8b10b encoding

- | Each byte is transmitted encoded as 10 bits
- | Encoding designed so there are never more than a few bits of the same polarity in a row
- | Avoids a DC spectral line
- | Guarantees enough transitions to do clock recover



Review: Payload Types

- | There are 4 types of payload sent on Fox-1A-D:
 1. Real-time health telemetry
 2. Minimum value health telemetry
 3. Maximum value health telemetry
 4. Science Telemetry
- | Types 1, 2, and 3 all have some common data
 - » For example temps, voltages
- | Each has some unique data
 - » For example MIN and MAX have the time of the last change
 - » All have various unique status bits



Fox-1E (aka RadFxSat-2) Telemetry

- | Fox-1E is a 30KHz linear transponder
- | Beacon/Telemetry below the pass band
- | 1200 bits per second BPSK
- | More data requires more FEC check blocks (interleaved)
- | Still uses 8b10b encoding
- | Transmitted differentially, i.e. 0 means the same bit as before, 1 means change bits (or vice versa)



Fox-1e BPSK Telemetry

- | BPSK = Binary Phase Shift Keying
 - » Essentially a sine wave whose phase is shifted





Fox-1E Frames

- | Built on DUV frames concept
- | Each frame starts with header
 - » Payload type number becomes frame type number
 - » Each frame type has a fixed order of payloads within
- | Each frame ends with FEC check blocks
- | Each frame is encoded with 8b10b



Frames and Payloads

- | Fox-1A-D frames and payloads were about the same
- | Fox-1E there is a difference
 - » Frame is still about 5 seconds
 - » Frame still has 1 header, 1 (set of) FEC check blocks
 - » But frame contains 6 sets of data called payloads
- | Fox-1E payload types are the same as DUV +
 - » Two additional types, 5 and 6, called Health WOD¹ and Science WOD

¹ Whole Orbit Data (more later)



Fox-1E Frames

Header <i>Satellite Number</i> <i>Satellite Time</i> <i>Frame Type</i>
Payload 1
Payload 2
Payload 3
Payload 4
Payload 5
Payload 6
FEC Check Block



Frame Types vs Payload Types

- | Frame type 0 (All WOD):
 - » Payloads 6 5 6 5 6 5
- | Frame type 1 (Real Time)
 - » Payloads 6 5 6 5 1 4
- | Frame type 2 (Min-Max)
 - » Payloads 6 5 6 5 2 3
- | Frame type 3 (Real Time Beacon)
 - » Payloads 1 5 5 5 5 5
- | Frame type 4 (WOD Beacon)
 - » Payloads 5 5 5 5 5 5



What is WOD?

- | WOD means Whole Orbit Data
- | What can we do with 6X data rate and not many additional sensors?
 - » Answer: Send data when in range of a ground station that was collected earlier in the orbit
- | But we don't know when there is a ground station!
 - » Answer: Send the same data over and over and over...

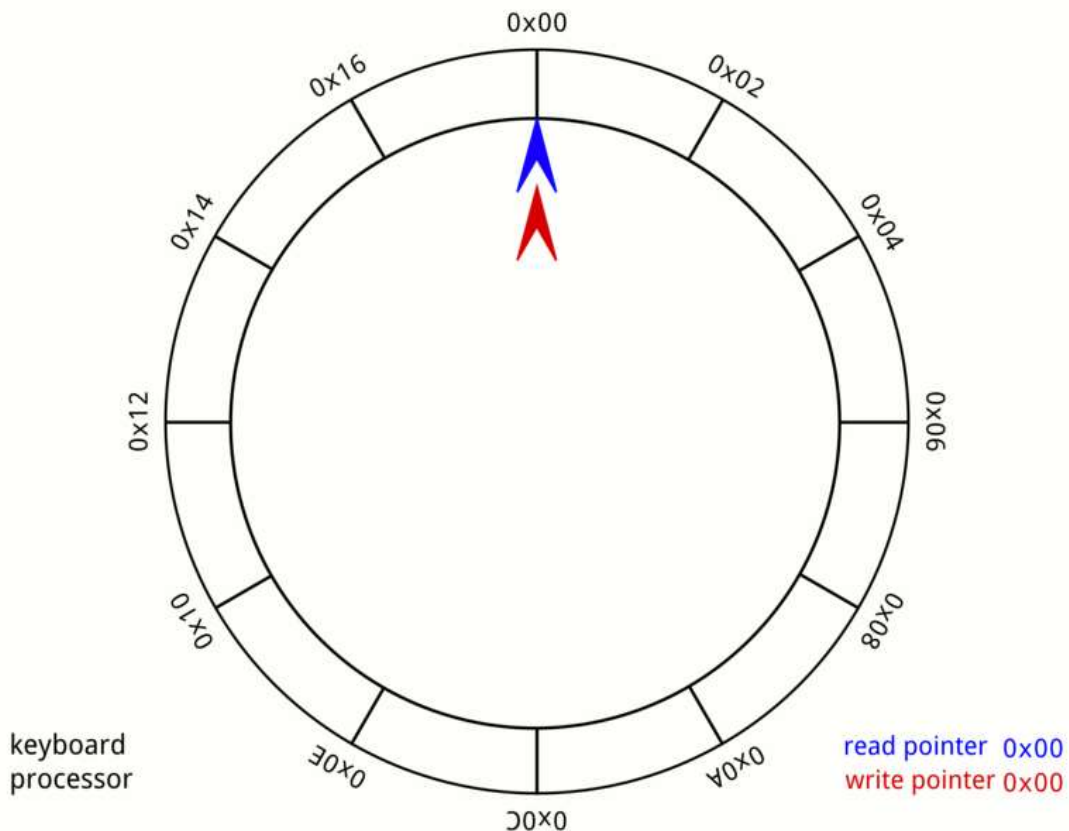


How We Do WOD

- | All Foxes have “MRAM” non-volatile memory
 - » Essentially infinite write cycles
 - » High tolerance to radiation
- | FM Foxes use it for ‘Voice of Fox’
- | Fox-1E stores WOD
- | MRAM organized as a circular buffer
- | Collect data 1/minute and store in MRAM
- | Transmit 31 data packets for each one that is collected

Ring Buffer

Type=Collect Data
Read=Send to ground



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How Much WOD To Save?

- | Surprising Truth

- » No matter how big the memory, we still transmit each WOD packet the same number of times (31)

- | Consider:

- » If we have a small amount of memory a given packet is sent more frequently, but does not stay in the S/C as long and thus does not see as many ground stations
- » With more memory, a given packet is sent less frequently, but spread over a wider area on earth?

- | How much memory use is optimal?

Carl Wick, N5MIM, found out!



A WOD Simulation-Carl Wick

- | We wanted to answer these questions:
 - » How much data should be stored on board to ensure all is received on Earth somewhere?
 - » How often must data be transmitted to ensure reception?
 - » What are the driving system factors in a WOD design?

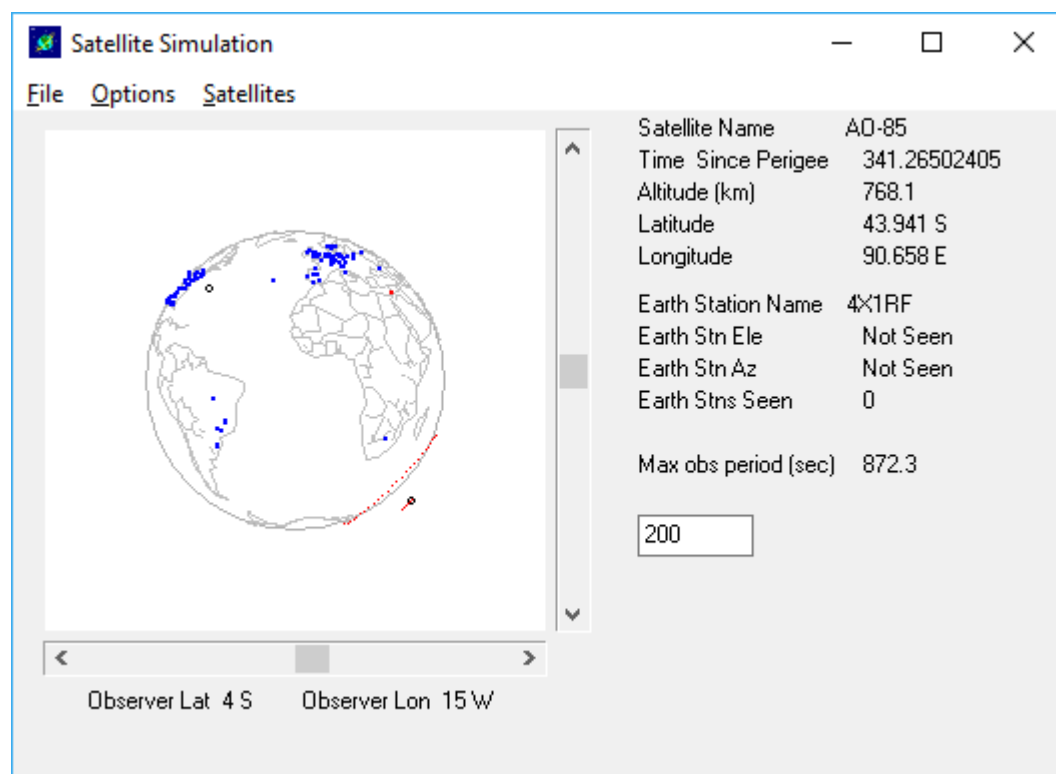


A WOD Simulation

- | A realistic simulation of satellite track and WOD system can help answer these questions.
 - » Start with a known orbit model to predict orbit paths over a period of time
 - » Add in known ground station locations
 - » Use the orbit model and a statistical reception model to predict when messages could be received.
 - » Change satellite WOD queue length and other parameters to find the best solution

A WOD Simulation

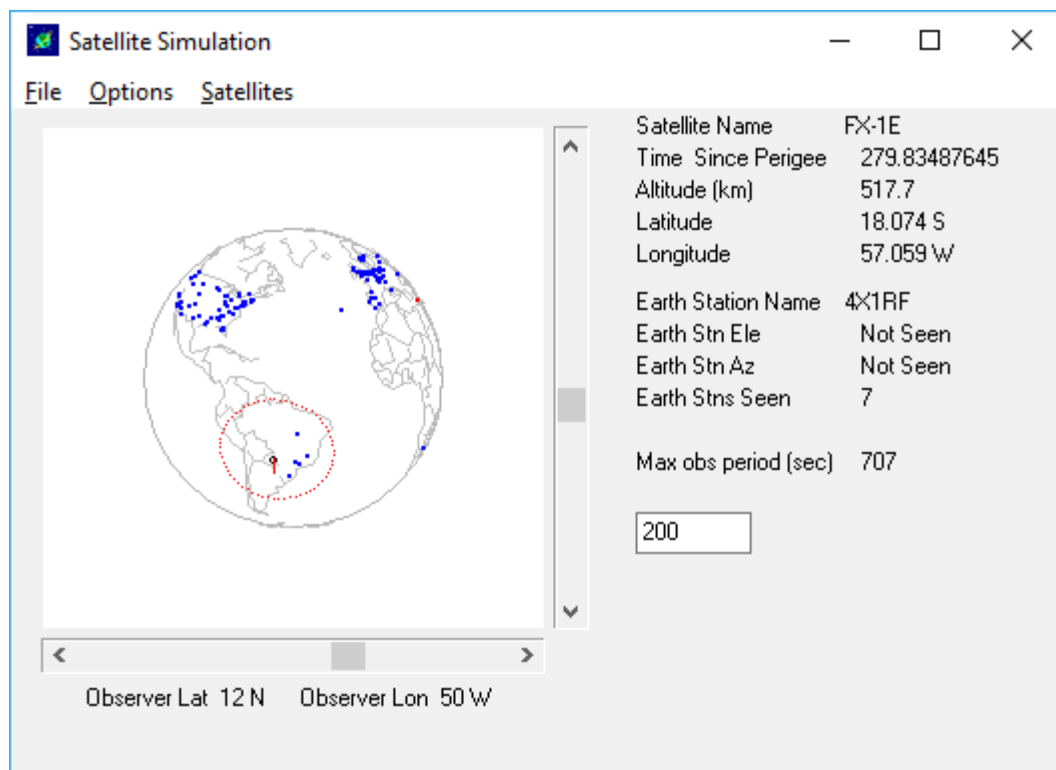
- Start with a standard NORAD LEO orbit prediction model to build an orbit simulation





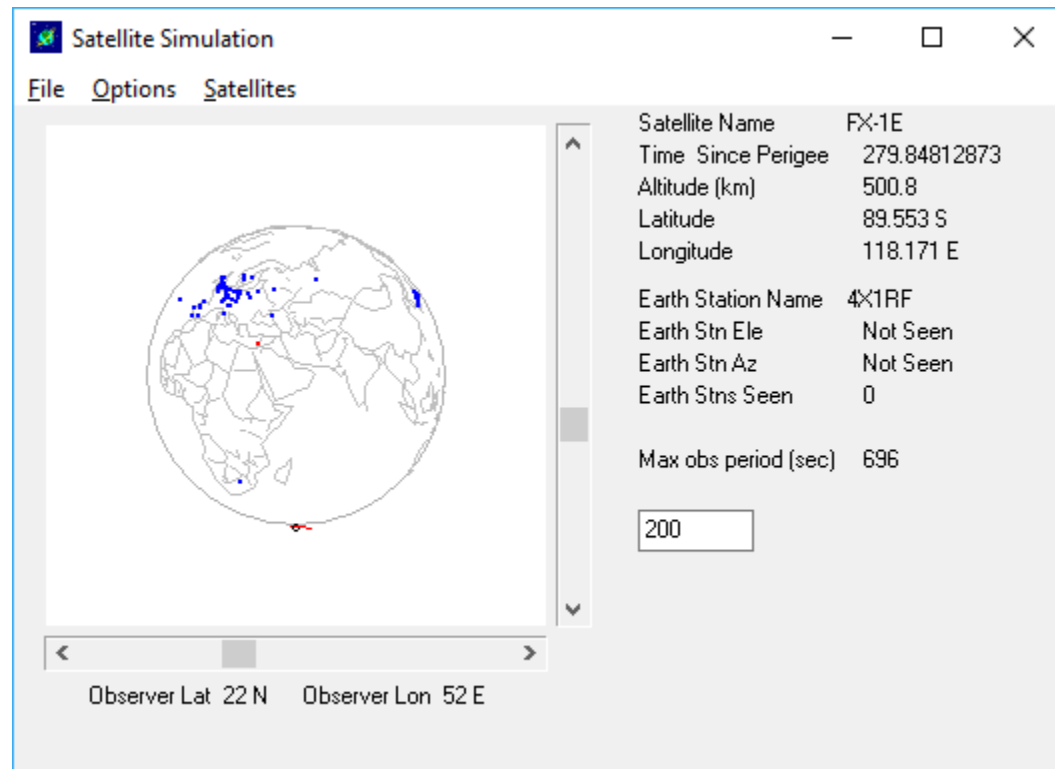
A WOD Simulation

- Add in known ground stations that regularly contribute to AMSAT efforts (blue dots = 200+ stations)



A WOD Simulation

- Contributing ground stations are highly clustered in just a few locations (NA, W. Europe, Japan)



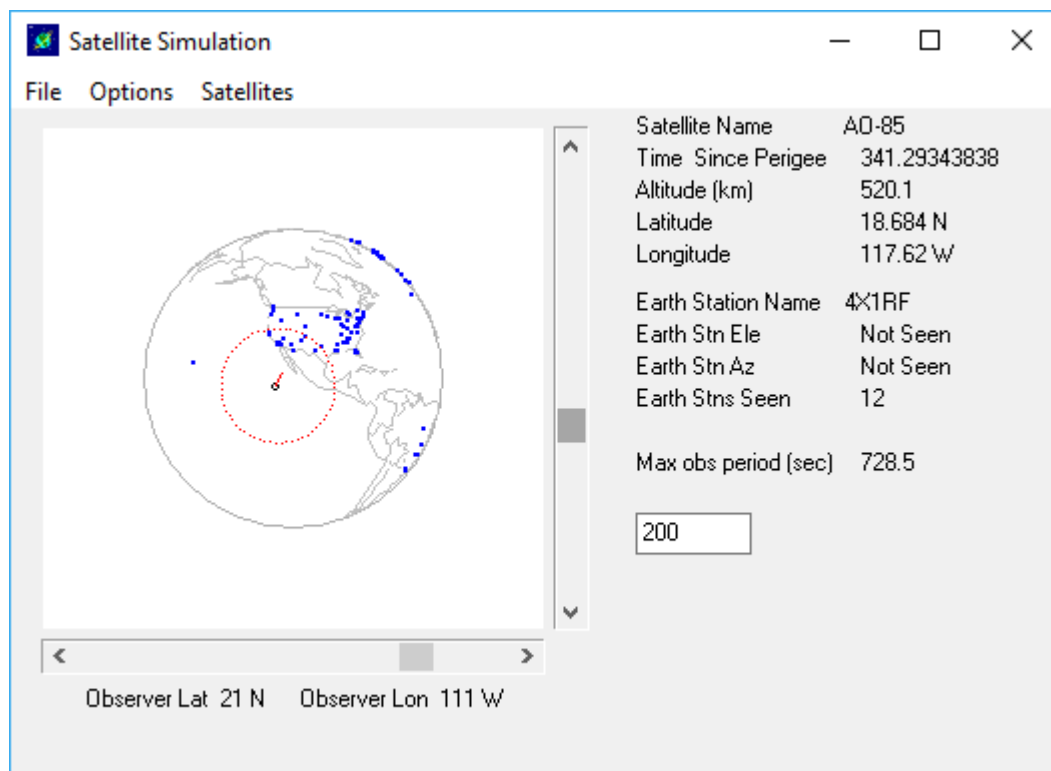


A WOD Simulation

- | Simulation provides the footprint of a selected satellite over the earth at any instant
- | To receive a transmission a satellite footprint must overlap a station for an entire message
- | Probability of actual reception is also a function of elevation (angle from ground station to satellite)

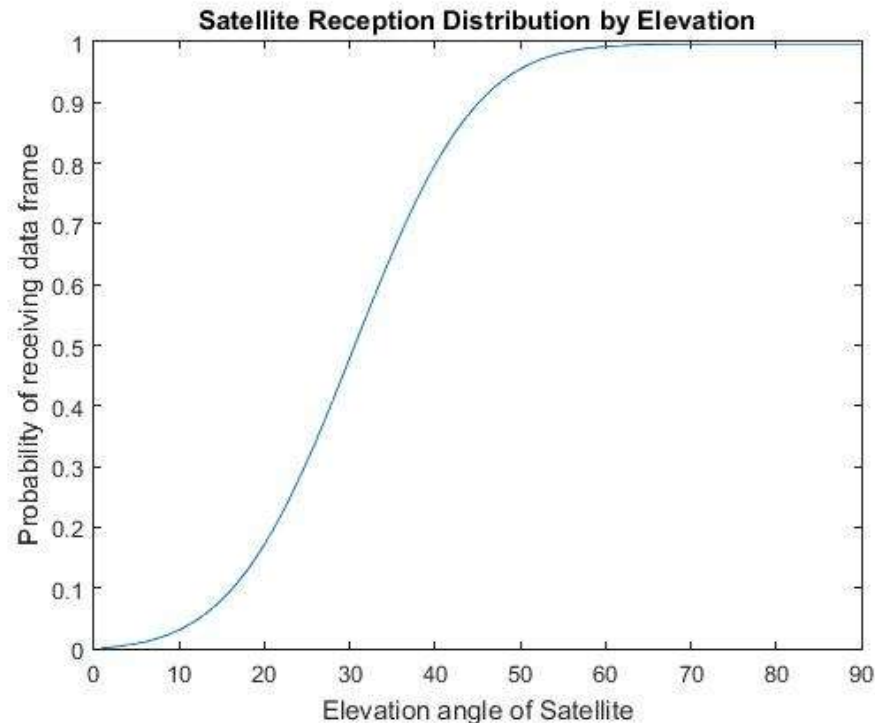
A WOD Simulation

- Actual reception is a statistical function of elevation. Higher elevation – higher probability of successful reception of WOD



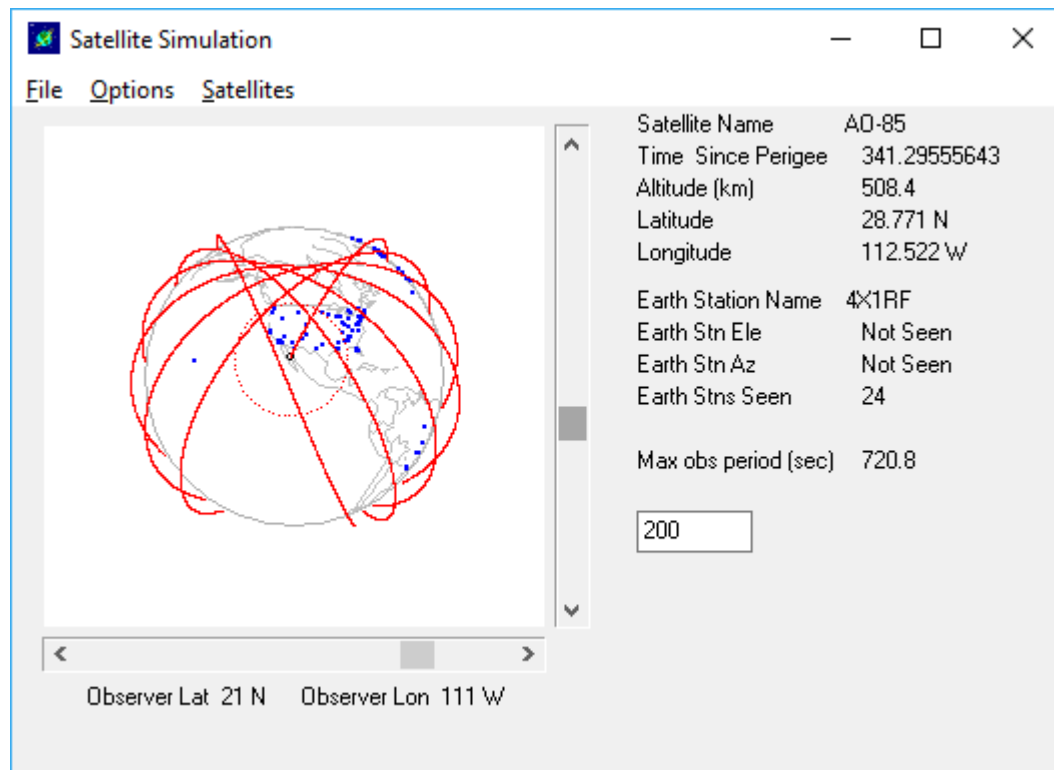
A WOD Simulation

- Likelihood Function used in the simulation. As satellite elevation increases, so does the probability of receiving a WOD frame.



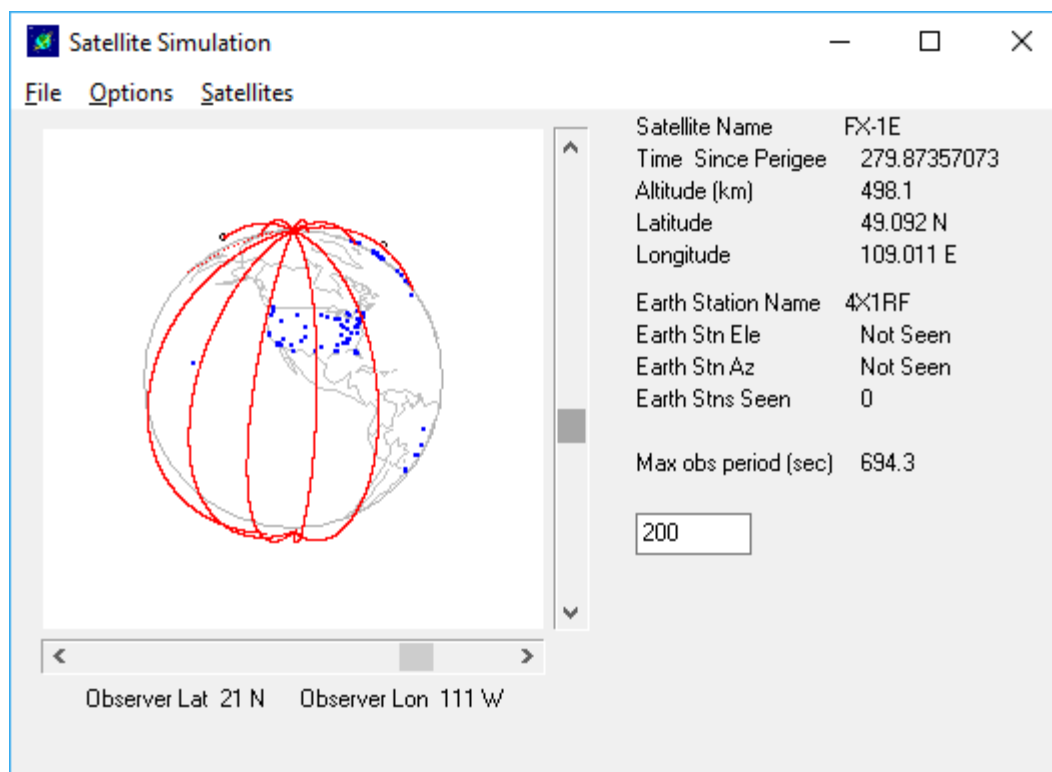
A WOD Simulation

- Simulation: orbits are predicted for a 24 hour period. Files keep data on when WOD could be statistically received based on concentration of stations and elevation



A WOD Simulation

I “What-if” simulation using a polar orbit



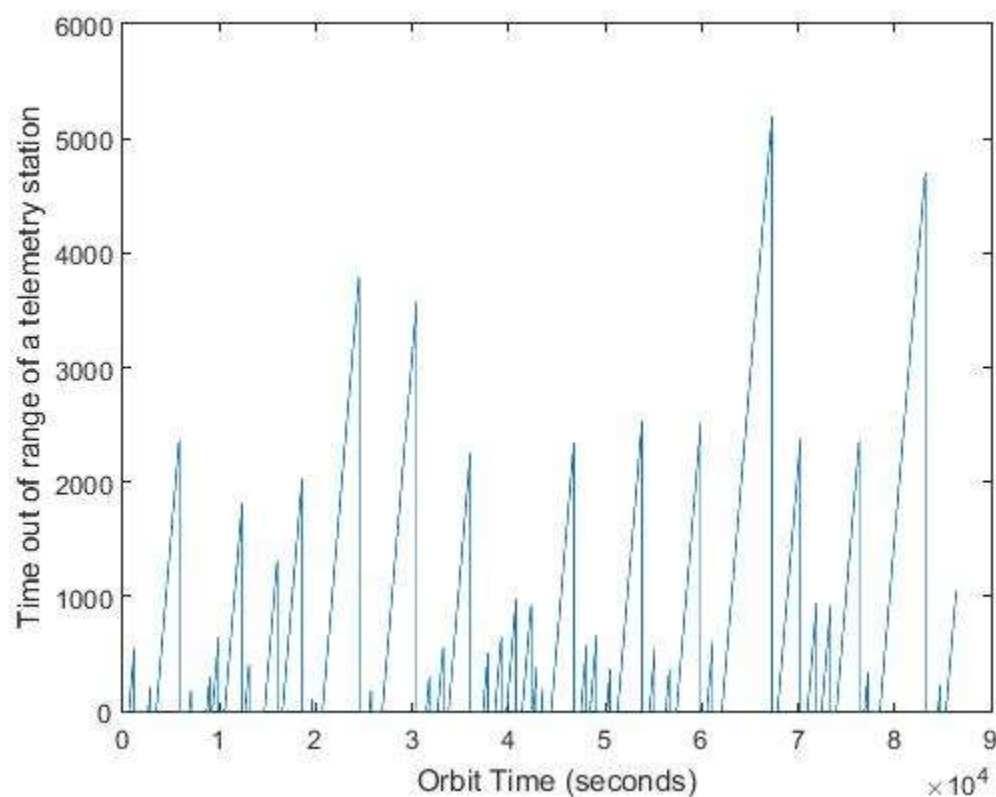


A WOD Simulation

- | A simulation run takes approximately 15 seconds on a desktop computer
- | Satellite queue lengths are adjusted until minimum data is lost (never received at a station while in the satellite queue)
- | Factors are orbit plane (polar orbit is better), distribution of earth stations, length of queue, number of messages sent per unit time)

A WOD Simulation

- Example data: accumulated seconds during orbits that a satellite is out of range of any ground station



- | The remaining question: What is a good circular buffer size in the satellite?
- | Is there an optimal?



And the answer??



And the answer??

42!!!



And the answer??

42!!!

No wait---answer to the wrong question



And the answer??

The Actual Answer: **150!**

More made little difference



Back to Fox-1E

- | Fox-1E has a circular buffer than can hold 150 WOD data records
- | That would be somewhere over 1-1/2 orbits
- | Each one gets sent 31 times over the course of 150 minutes.
- | (Backup: We can command the size larger and smaller)



Credits

- | Carl Wick, N3MIM -- WOD Simulation
 - » See paper in 2017 Symposium Proceedings
- | Chris Thompson, AC2CZ/G0KLZ – FoxTelem
 - » See GitHub/AC2CZ/FoxTelem
- | Phil Karn, KA9Q et al – Telemetry encoding and FEC
 - » See references in W2BFJ 2017 Symposium Paper
- | Mike McCann K2GHZ – WOD Initial Proposal
 - » See references in W2BFJ 2017 Symposium Paper
- | Burns Fisher, W2BFJ – Fox Telemetry Transmission
 - » See paper in 2017 Symposium Proceedings